A design and application of compound multi-functional sensor in wood-based panel processing

XU Kai-hong[1,2] and ZHOU Ding-guo[1]

[1.] Nanjing Forestry University, Nanjing 210037, P. R. China

[2.] Northeast Forestry University, Harbin 150040, P. R.. China

Abstract: A compound multi-functional sensor was designed by the study on the on-line testing technology of wood-based panels, and its properties of shape, functions, size, resistance to special environment were studied in details. The operational principles of different sensors, technical flow of manufacturing, development of software systems of special functions, and the assessments of technical specification were also be introduced. This sensor adopted many new technologies, such as the applications of piezoresistant effect and heat sensitive effect can effectively measure the pressure and temperature, digital signal processing technology was used to extract and treat signals, and resist interference, encapsulation technology was used to keep the normal run of sensor under a harsh environment. Thus, the on-line compound multi-functional temperature/pressure sensor can be applied better to supervise the production of wood-based panels. All technical specifications of the compound multi-functional sensor were tested and the results met the requirements of the equipments.

Keywords: Wood-based panel processing; Multi-functional sensor; Piezoresistant effect; Heat sensitive effect

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Introduction

Multi-functional sensor, a new developmental direction of sensor field, can integrate several sense organs to measure several parameters at one time (Liu 1999). This sensor not only has small size but also has strong functions. Moreover, the collected data is very concentration and easy to process (Yuan 2002). Nowadays some correlative research is conducted and has made many breakthroughs in this field (Ye *et al*. 2000; Xu *et al*. 1999). The online testing of wood-based panels by multi-functional sensor has been widely developed abroad, however this technology isn't applied in China now. Hot pressing is a key step in the process of processing wood-based panels, which has an important action to the final quality and yield of products (Ji *et al*. 1999). It mainly consists of the three elements of pressure, temperature, time (Hu *et al*. 2004; Peng and Fan 2000). The controlling section in wood-based panels processing mainly depends on the testing data of temperature and pressure. If we can test these data by real-time online, which will greatly advance the efficiency and quality of wood-based panels product. Therefore, it is necessary for us to design a set of multi-functional sensor with the performances of high precision, small, size and stronger function. This study designed a set of multi-functional sensor applied to hot-press, and it has above properties.

Operational principle of the compound multi-functional sensor

Operational principle of piezoresistant sensor

Piezoresistant sensor is made up on the principle of piezoresistance effect of single crystal silicon materials, and the piezoresistance effect is that the resistance of single crystal silicon materials would be changed when it encounters the outside force. According to Ohm law, the resistance of semiconductor material (R) can be denoted by the following equation:

$$R = \rho L / A \tag{1}$$

After calculus calculation, we could obtain the Eq. (2):

$$\frac{dR}{R} = \frac{d\rho}{\rho} + (1 + 2\mu)\frac{dL}{L} \tag{2}$$

Inducting Eq. (3)

$$\frac{d\rho}{\rho} = \pi\sigma \tag{3}$$

Then get another form of Eq. (2) as follows:

$$\frac{dR}{R} = \pi\sigma + (1 + 2\mu)\frac{dL}{L} = (\pi E + 1 + 2\mu)\varepsilon = K\varepsilon \tag{4}$$

As far as semiconductor materials are concerned, the value of $\pi\sigma$ is far more than that of the $(1+2\mu)$, so the latter can be ignored. Correspondingly the change of material resistance can be denoted as follows:

$$\Delta R/R = \Delta\rho/\rho = \pi\sigma \tag{5}$$

In above equations, A is transverse area of materials, L is length of materials, Π piezoresistant modulus, σ stress, ρ is modulus of semiconductor materials.

According to the Equation (5), change rate of semiconductor materials ($\Delta R/R$) is mainly caused by piezoresistant effect ($\Delta\rho/\rho$). Four P type resistances are spread onto N type silicon membrane to form Wheatstone bridge which constitutes silicon Piezoresistance chip, and then the change of pressure can be transformed into the change of resistance.

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Biography: XU Kai-hong(1969-), Male, associate professor, postdoctoral of Nanjing Forestry University. Mainly majors in detecting technology on reproducible resources' research and application. E-mail: xkh@vip.0451.com

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Operational principle of platinum membrane resistance temperature sensor

Platinum membrane resistance temperature sensor is based on the peculiarity of membrane resistance that attached to alumina porcelain whose resistance can be changed with outside temperature. The sensor can be used to measure average temperature of medium in the spectrum (Chen *et al*. 2001)

The correlation between platinum membrane resistance and temperature can be denoted by following equation:

$$R_t = R_0(1 + At + Bt^2 + Ct^3 + \cdots\cdots) \qquad (6)$$

Where, R_0 is the value of platinum membrane resistance at the temperature of 0ºC (Ω), R_t is the value of platinum membrane resistance at the temperature of t ºC (Ω), t is the temperature of medium under testing (℃), and A, B, C …… are relevant constant that can be determined by experiment.

$A=3.96847\times10^{-3}$/ºC; $B=-5.847\times10^{-7}$/ ºC^2; $C=-4.22\times10^{-12}$/ ºC^3

In the spectrum of –50–600ºC, the correlation between resistance and temperature can be shown by Eqs. 7 and 8.

$$R_t = R_O(1 + At + Bt^2) \quad (0\text{–}600\ ºC) \qquad (7)$$

$$R_t = R_O\left[1 - At + Bt^2 + C(t-100)t^3\right] \quad (-50\text{–}0\ ºC) \qquad (8)$$

With respect to Pt100 platinum membrane resistance:

$$R_O = 100 \pm 0.12(\Omega) \qquad (9)$$

Design of compound multi-functional sensor

Design of pressure and heat sensor

As piezoresistant sensor can be largely affected by the outside temperature, and it runs under the high temperature of hot pressing. Thus, it is necessary to adjust Wheatstone bridge to improve the temperature characteristics of sensor. The circuit illustrated in Fig. 1 can compensate precision of piezoresistant sensor to a proper level. It may adjust the maladjustments and sensitivity of temperature excursions. The temperature excursions brought about by full output of quota are related to sensitivity excursion, and these two parameter's temperature characteristics are in direct ratio each other. The resistance used to zero is intended to compensate the voltage maladjustment of sensor at room temperature. Resistance R_{TS} and R_{TZ} (or R'_{TZ}) are used to revise temperature error. Because the resistance of bridge increases with the increase of outside temperature, which make also two ends of voltages of sensor increase, and this increasing voltage will make the sensitivity of sensor increase. In other words, on a given voltage it will output higher voltage. If two ends of voltages are kept constant the sensitivity of sensor will reduce with the increase of temperature. When the increase of bridge resistance is caused by temperature, the positive change modulus of sensitivity is higher than negative sensitive modulus, therefore, output of full quota is aped to increase with temperature increasing. In order to counteract such effect, resistance R_{15} is applied to branch some bridge electricity. Similarly, R_{TZ} or R'_{TZ} can adjust the excursion of maladjustment and which one of them is applied is determined by the direction of temperature excursion. Considering the practical requirement, temperature and pressure sensors are outputted in the form of 4-20mA which can convey a long distance and improve the anti-jamming ability.

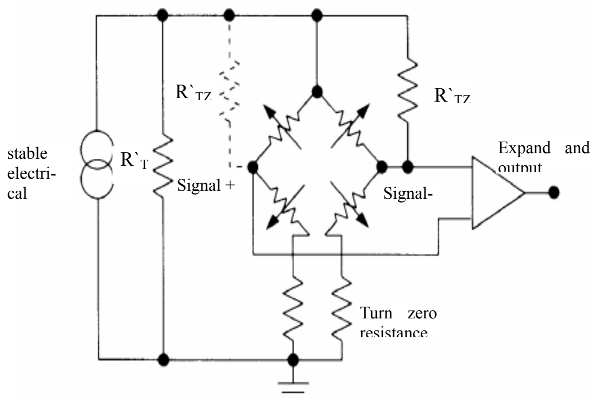

Fig. 1 Working principle of piezoresistant sensor's temperature compensation

Design of monitor controller

Monitor controller has the functions of collecting, transferring, displaying test data and provides an interface with outside. Because there are two test feeding passages, based on the design principle it is necessary to apply SCM (ADUC812) which is inserted with 8 passages and 12 digital AD switch. This chip includes self-adjusting high-powered ADC, two 12 digital DAC and 8 digital MCU which is programmable (also is compatible with 8051). Moreover, there are 8K bits flash/EE program storage, 640 bits flash/EE data storage and 256 bits data SRAM which could support online programming. Furthermore, MCU has watchdog timer (WOT), electrical source displaying (PSM) and ADC DMA functions which provide 32 programmable I/O for multiprocessor access and I/O's further expansion, SPI (It is compatible with I^2C) and standard UART parallel I/O (also including other variety of parallel and serial industry ports). MCU kernel stimulant switch has normal, free and power off modes. It supplies a flexible management scheme of low-power electrical source. This apparatus takes plastic square flat encapsulation form which may work in the industry temperature scope by two voltages of 3V and 5V and supplies operators with multi-passages switch , track/follow inner chip norm, adjustment peculiarity, and A/D switch (Wuhan Liyuan Electronics Ltd. 1999). Because this apparatus is high integration it can meet the requirement of precision and economy. Applying I^2C bus liquid crystal driving chip can expand displaying digit and reduce the system resources, which were required because if one digit is only displayed with one digital displaying driving circuit, many digits will take up much I/O resources. Operational principle of displaying controller is illustrated as Fig. 2.

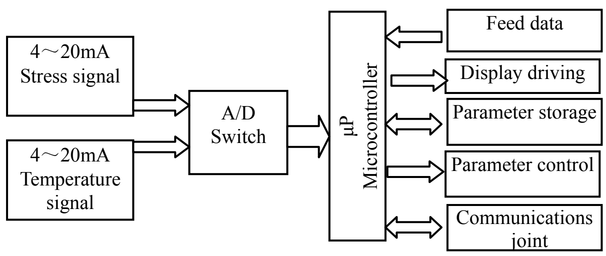

Fig. 2 Displaying controller's structure

Scheme of system exploitation

When SCM application system is programmed, assemble lan-

guage is a common tool, it can directly and quickly operate hardware, but the inherent format of its repertoire is also restricted by hardware structure, thus it is difficult to program, mediate and transplant (He 1996). With the capability improvement of SCM, working speed is accelerated and the programming efficiency is also more emphasized.

Franklin C51, an advanced C programming language comilation, is specially designed for 80C51 serial SCM. Applying Franklin C51 can shorten the exploiting period of software, reduce exploiting expense, moreover, the corresponding system has high reliability and transplant, and maintains easily. The use efficiencies of above all the code are equivalent to assemble language. C language supplies a self-contained standardization flow controlling structure, and the complicated program can be divided into several modules, which makes the program easier to manage. The complicated system in this experiment was implemented easily by C51 programme (Zhang 1997). In order to obtain more accurate results, the linear compensation on the data collected by A/D switch needs to be conducted by software. The concrete method is as follows: Firstly, set up ideal beeline equation; secondly, analyze the practical data and find out error to be adjusted by beeline equation. As for current stimulant feeding the value after linear adjustment is equal to stimulant feeding value plus error adjustment value, and the linearity after software compensation can be improved into the scope of 0.005%.

Key technology

Digital noise

As in digital circuit there are many multi-passage switches whose frequent switch is the main source of digital noise, and some noise signal of stimulant circuit can be coupled into digital circuit through electricity, which makes the digital noise signal complicated. Moreover, these noise signals can make error for sampling results. So it is very meaningful to leach the noise signal in improving system precision. The concrete measures should be considered from two aspects: one, enhancing electrical source segregation of stimulant and digital circuits from hardware circuit; the other, applying digital filter technology to improve test precision.

Software programming

As for multi-input-output system, the software time succession is very important to secure quick responding time. Meanwhile, the linear compensation for input sampling results strength the operation capacity of system. Thus it is a key step of designing a good software structure to gain a more effective application.

The running environments of sensor and displaying controller are bad sharply, and various interferences can affect the run of sensor. Thus, it is very important to improve the own recovery capability of software for interferences. In order to implement a more exact measurement for sensor signal and erase the noise and interference in the signal, this displaying controller applies a software fault-tolerant technology, command redundance, and establishes a software trap to reduce the possibility of procedure ball flies and error actions. The application of digital filter technology can filter sharply impulse and small random interference.

Sensor encapsulation technology

Compound multi-functional heat/stress sensor has many performances, such as small size, high precision and stability. Exact encapsulation technology is a key to secure the quick responding of sensor. Encapsulation technics flow includes: design, bonding, ablution, and insertion of heat conducting medium, vacuum stress, solidifying of anti-heat-stress mobile carcass, and so on. Of them, the design of anti-heat-stress mobile carcass is the key section, which must meet space and all technics indices requirements of sensor (Gong 1989).

Testing method and results

The multi-functional heat/stress sensor was tested according to Q/UN 20157-2001 (Stress/heat composite sensor displaying controller regulations), the testing results showed that the performance of sensor can reach the standard (Table 1 and Table 2).

Table 1 Main technical performance indexes of sensor

Item		Zero output	Full output	Precision	Excursion %FS/H
criterion	temperature	4±0.4mA	18.4±0.4mA	±0.5℃	0.1
	stress	4±0.4mA	20±0.4mA	0.2%	0.1
1 test	temperature	4.10mA	15.9mA	0.4℃	0.09
	stress	4.08mA	19.8mA	0.6%	0.05
2 test	temperature	4.11mA	18.2mA	0.4℃	0.08
	stress	4.03mA	19.9mA	0.5%	0.05

Table 2 Testing results of sensor

Item		High temperature storage	Low temperature storage	High temperature working	Low temperature working	Random vibration	Impulsion
1	temperature	4.1mA	4.1mA	4.1mA	4.1mA	4.1mA	3.9mA
	Stress	4.1mA	4.2mA	4.08mA	4.08mA	4.08mA	3.98mA
2	temperature	4.13mA	4.13mA	4.13mA	4.13mA	4.13mA	4.01mA
	Stress	4.08mA	4.1mA	4.15mA	4.15mA	4.15mA	4.05mA

Conclusions

With the development of sensor in miniaturation, intelligentize and multifunction, the application of sensor in the field of signal detection will more and more comprehensive and be unique features. Compound multi-functional sensor is a new developmental direction of sensor technology. As the conditions of high temperature and pressure during the process of the wood-based panels processing, the common sensors are difficult to meet the requirements of the testing. This study successfully applied piezoresistant effect and heat sensitive effect to measure the pressure and temperature, digital signal processing technology to extract and treat signals, encapsulation technology to resist harsh environment to make new stable, precious, compact, low expense sensor, which can meet the requirement of online testing of

wood-based panels. By practical application this new sensor can obtain exact data during the process of hot pressing to improve and revise the technics of wood-based panels, and increase the quality of wood-based panels.

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